Mid-Frequency Bottom Scattering Model Development and Validation

Lisa M. Zurk
PO Box 751-ECE, Portland State University, Portland, OR 97201
phone: (503) 725-5423 fax: (503) 725-3807 email: zurkl@cecs.pdx.edu

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LONG-TERM GOALS

The propagation of mid-frequency (1-10 kHz) acoustic waves in shallow water regions (depths of 100-200 m) is strongly influenced by the characteristics of the ocean bottom. While there has been much progress in developing and validating bottom scattering models, much of the focus has been in the high frequency regime with comparatively less focus in the mid-frequency. This is an important topic, since in the mid-frequency regime the acoustic field can penetrate the rough interface into the sediment and undergo multiple scattering from sediment stratification and volume inhomogeneities. In this work, the long-term goal is to develop an understanding of the spatial and temporal characteristics of the acoustic field through a rigorous modeling and measurement effort. In addition, the feasibility of using tools such as a chirp sonar for bottom characterization will be considered and assessed.

OBJECTIVES

The objective of this research is to examine the acoustic scattering physics in the mid-frequency regime to isolate and characterize the scattering contributions due to bottom roughness, sediment stratification, and embedded volume scatterers. A further objective is to evaluate the use of a chirp sonar system for characterization of the ocean bottom. This will provide a means for accurately quantifying parameters such as reflection losses and bottom penetration over a broad frequency range in support of Navy sonar applications.

APPROACH

The technical approach for this work is as follows. First, advances within the electromagnetic community will be exploited by considering computationally efficient models for scattering in layered inhomogeneous media, as well as various approaches for inversion of layer parameters. Candidates from this process will be employed to address the underwater acoustic propagation into the ocean bottom, taking into account the shear effects that may arise from an elastic bottom. Both surface and volume scattering – and mixed scattering – will be considered. Finally, models for scattering in the ocean bottom will be validated with data from the Shallow Water 2006 experiment (SW06) that took place in August 2006. The data from SW06 includes chirp sonar returns that provide information on the bottom substructure, and which were obtained in conjunction with careful characterization of bottom roughness and sediment layers. The chirp sonar was operated by Dr. Altan Turgut (NRL) and the mid-frequency bottom characterization was performed by Dr. DJ Tang (APL/UW). A Portland State University PhD student, Jorge Quijano, participated in SW06 and assisted with the measurements. Jorge is just beginning his PhD program (under Dr. Lisa Zurk) in the area of acoustic scattering models for ocean bottom characterization, and is supported by this ONR grant. Dr. Dan Rouseff (APL/UW) is on Jorge’s committee, and is providing additional technical guidance.

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WORK COMPLETED

The work completed during this first (partial) year of effort is as follows:

- Survey of scattering models. Several classes of numerical models exist in the electromagnetics (and acoustics) community, and some of the most widely used are: Finite Difference Time Domain (FDTD), Finite Element Method (FEM), and Method of Moments (MoM). The choice of model depends on the size of the problem domain, the nature of the inhomogeneities, and the desired bandwidth for calculation. For the ocean bottom scattering problem, FDTD has several advantages, including simplicity of the formulation, the ability to model a broadband signal, the ability to model arbitrary geometries, and recent advances in computationally efficient implementations. For analytical models, there are several choices for estimating the approximate solution for rough surface scattering and volume scattering. For this work, the Kirchhoff approximation and Mie scattering theory were used to provide analytic checks for simple isolated scattering geometries.

- Layered media formulation. Although numerical models can provide a numerically exact answer, they do not provide the ability to understand and differentiate returns from different scattering mechanisms (for example, interface layers versus volume scatterers). In order to characterize the bottom properties from a chirp sonar return, an analytical model that included the multiple scattering is desired. One model widely used in passive remote sensing is Radiative Transfer theory (which is an integro-differential equation for the diffuse intensity) and solutions have been developed for inclusions of spherical and cylindrical scatterers. Densely packed scatterers can result in multiple scattering which is handled via a variation of the RT formulation, the Dense Media Radiative Transfer equations (DMRT). Some investigators have further employed a technique called layer stripping, which de-couples the time-dependent returns to re-construct a layered media. For this work, the Radiative Transfer formulation will be used to analyze the ocean bottom returns, and a modified layer stripping technique applied to recover layer properties.

- Participation in SW06. Portland State University PhD student, Jorge Quijano, participated in the SW06 experiment on the R/V Knorr. He assisted with measurements, data logging, and documentation. Some initial data from SW06 is shown in the following section.

RESULTS

During this initial portion of the research effort, a survey of numerical techniques for computing wave scattering in random media was completed, and the Finite Difference Time Domain (FDTD) was identified as the best candidate for numerical computation of acoustic energy into the ocean bottom. Furthermore, two specific approaches have emerged as viable candidates for understanding the sonar echoes from a layered ocean bottom: the Radiative Transfer (RT) theory and layer stripping approach. Although RT is commonly applied for remote sensing applications, it does not appear to have been considered for use in interpreting pulse returns (such as a chirp sonar) for ocean bottom mapping.

During the Shallow Water 2006 (SW06) experiment, a chirp sonar system was employed (by Dr. Altan Turgut, NRL) as shown in Figure 1. The chirp was operated with three different signals: a single tone

(3.5 kHz, pulse length=2 ms), a short chirp (3 kHz to 4 kHz, pulse length=20 ms), and a long chirp (3 kHz to 4 kHz, pulse length=50 ms). The signals were received on phones of a vertical line array (VLA), match filtered, and stacked to produce the bottom profiles shown in Figure 2 (depth of zero denotes the top of the ocean bottom). As can be seen from the figure, there appears to be definite bottom structure, with slowly varying interface layers.

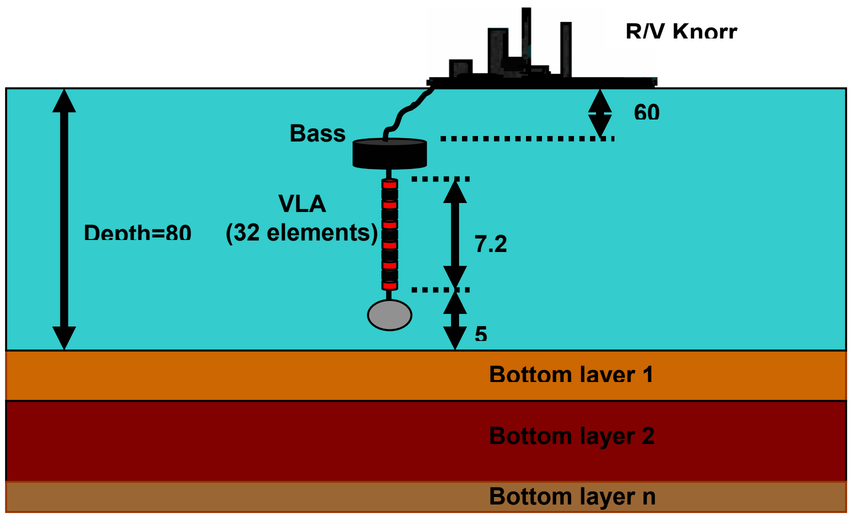

Figure 1. Diagram showing the experimental set-up during SW06. The water depth was approximately 80 m, and the research vessel deployed BASS (a 3-axis acoustic current meter cage developed by WHOI) at a depth of 60 m with a 32-element VLA. The chirp sonar produced acoustic energy that penetrated the ocean bottom layers.

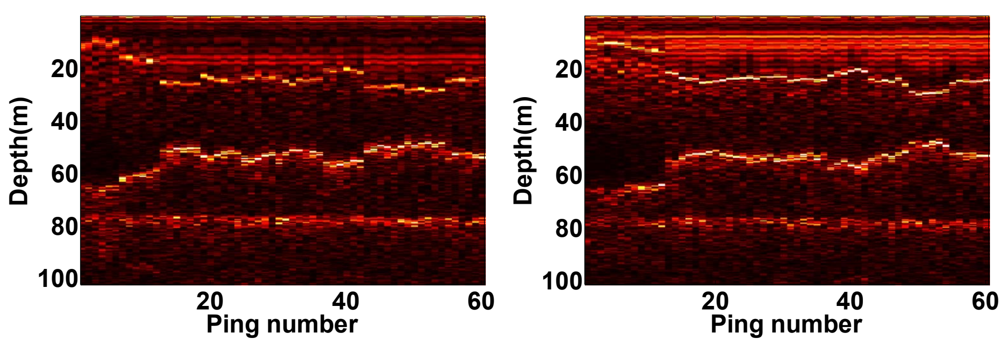

Figure 2. Bottom profiles obtained during SW06 over 60 pings. Left-hand image was produced with a long chirp signal and right-hand image was produced with a short chirp. Both images show strong interface layers in the sediments at depths of 30, 60 and 80 meters below the water-sediment interface.

IMPACT/APPLICATIONS

Many Navy sonar systems operate in the mid-frequency (1-10 kHz) band (for example, surface ship active ASW, SQS 53). In shallow water regions (depths of 100-200 m) the performance of these systems is strongly influenced by the presence of environmental variability. The impact of this work is to provide an understanding of the spatial and temporal characteristics of the acoustic field in the mid-frequencies in order to optimize sonar performance.

RELATED PROJECTS

Physics-Based Processing for Sonar Mapping of Coral Reefs; (FY07, sponsored by the Nature Conservancy)